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AN EVALUATION OF HEATING AND EROSION IN THE 105MM XM204 HOWITZE--ETC(U)

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DAAA21-77-C-0023

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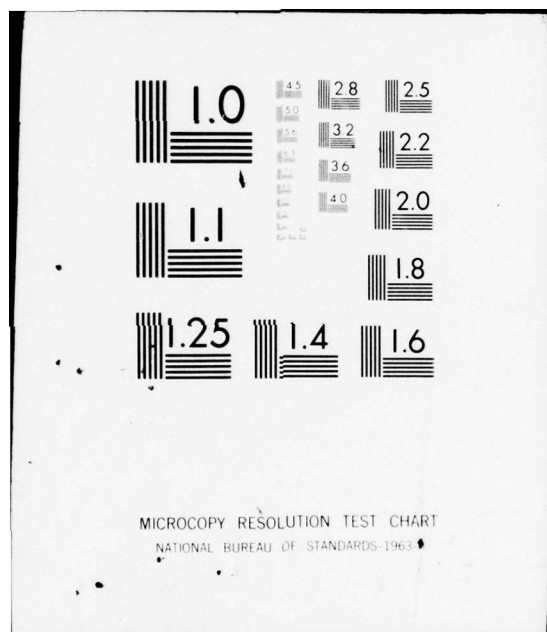
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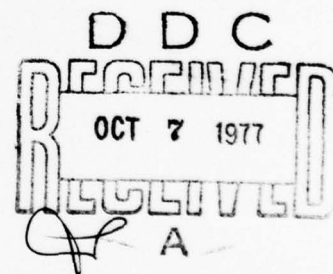
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AN EVALUATION OF HEATING AND EROSION IN THE
105mm XM204 HOWITZER AND 155mm M185 CANNON

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F.A. Vassallo

Calspan Technical Report No. VL-6050-D-1

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FOREWORD

This report was prepared by Calspan Corporation, Buffalo, New York, in partial fulfillment of work conducted under Contract No. DAAA21-77-C-0023. The work was sponsored by the Propellants and Explosives Branch of the Ammunition Development and Engineering Directorate, Picatinny Arsenal, Mr. Daniel Katz, Branch Chief.

Acknowledgement is hereby given to Mr. Joseph Kocur of Picatinny Arsenal and the gun crew of the test station whose timely efforts made completion of the test phase possible. Special thanks are given to Mr. Andrew Kocur, also of Picatinny, for his efforts in setting up and operating the sensitive recording instrumentation used in the test work.

The assistance of Messrs. Sandor Einstein and Harry Hassmann of Picatinny are gratefully acknowledged.

The author wishes to thank Calspan personnel, Mr. A. Ashby, Mr. J. Weibel, and Mr. W.R. Brown for their assistance in collection and reduction of test data.

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ABSTRACT

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An evaluation of heating and erosion of several candidate charges to be used in 155mm and 105mm tubes was performed. Test data were obtained in field testing of actual cannons using sensitive thermocouples and special Calspan erosion sensors. The following significant results were obtained:

155mm Cannon:

1. The charges employing the greatest additive showed erosion performance approaching that of the M119, whereas the original XM201E2 charge showed significantly higher erosion than the M119.
2. The XM201E2 charge employing 19 oz. internal wear additive resulted in less heat input at the origin and lower erosion than the other internal designs (of lower additive weight).
3. The 19 oz. internal additive design resulted in less heat input and the same erosion compared to the 12 oz. jacket (external) additive design.

105mm XM204 Howitzer:

1. Measured heating and erosion in this howitzer was found to be much lower than that of the 155mm cannon. Critical examination of all significant heating/erosion factors indicates the XM200 and XM622 to have about the same erosion performance with the XM200 charge showing very slightly lower heating.
- ↖

OBJECTIVE

The objective of the work was to gather data leading to an assessment of the heating and erosion in the:

1. 155mm, M185 cannon firing M119 and modified XM201E2 charges; and
2. 105mm, XM204 howitzer with comparison of Zone 8 charges XM200 and XM622.

TABLE OF CONTENTS

<u>Section</u>	<u>Title</u>	<u>Page No.</u>
	FOREWORD	i
	ABSTRACT	ii
	OBJECTIVE	iii
I	INTRODUCTION	1
II	TEST PREPARATIONS	3
	A. 155mm Cannon	3
	B. 105mm Howitzer	4
III	GENERAL TEST SCOPE AND PROCEDURES	6
	A. Test Scope	6
	1. 155mm Cannon	6
	2. 105mm Howitzer	8
	B. Data Reduction for Heat Input	8
IV	TEST RESULTS	10
	A. 155mm Cannon	10
	1. Total Heat Input	10
	2. Bore Erosion	13
	B. 105mm Howitzer	19
	1. Bore Heat Input	19
	2. Bore Erosion	22
V	REFERENCES	31

LIST OF FIGURES

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
1	COMPARISON OF STEEL EROSION SENSORS FOR M119 AND UNMODIFIED XM201E2 CHARGES (200X)	15
2	COMPARISON OF EROSION OF INCONEL SENSORS FOR M119 AND UNMODIFIED XM201E2 CHARGES (200X)	16
3	STEEL SENSOR SURFACE CONDITION BEFORE AND AFTER FIRING FOR TWO XM201E2 MODS INVOLVING INCREASED WEAR ADDITIVE (200X)	17
4	INCONEL SENSOR CONDITION BEFORE AND AFTER FIRING FOR TWO XM201E2 MODS INVOLVING INCREASED WEAR ADDITIVE (200X)	18
5	SURFACE CONDITION OF VASCOMAX SENSORS BEFORE AND AFTER FIRING FIVE M67 SHOTS (200X)	23
6	SURFACE CONDITION OF VASCOMAX SENSORS BEFORE AND AFTER FIVE XM200 SHOTS (200X)	24
7	SURFACE CONDITION OF VASCOMAX SENSORS BEFORE AND AFTER FIVE XM622 SHOTS (200X)	25
8	POST TEST SURFACE WAVE FORMATION ON VASCOMAX EROSION SENSORS LOCATED NEAR THE ORIGIN OF RIFLING (20X)	26
9	POST TEST SURFACE CRACK PATTERNS FOR VASCOMAX SENSORS LOCATED NEAR THE ORIGIN OF RIFLING (2000X)	29

LIST OF TABLES

<u>Table No.</u>	<u>Title</u>	<u>Page No.</u>
I	155MM TEST ROUNDS	7
II	155MM REDUCED BALLISTIC/HEATING TEST DATA	11
III	155MM BORE EROSION/CRACKING AT ORIGIN	14
IV	105MM REDUCED BALLISTIC/HEATING TEST DATA	20
V	ESTIMATED EROSION FACTORS	28
VI	RELATIVE EROSION PERFORMANCE	30

I. INTRODUCTION

In the development of a new ammunition charge, it is desirable to achieve maximum performance at the lowest possible cost. The XM201E2 charge was developed with this ultimate goal. Its use as a replacement for the M119 charge was expected to provide a cost reduction with improvement in performance. Cost reductions in the XM201E2 charge result from the use of base ignition rather than the more complex and costly center core ignition technique as used in the M119 charge.

A factor of importance in the use of a propelling charge is its influence on the life of the launch tube in which it is used. The earlier M119 charge utilized "cool" burning single-base M6 propellant in the charge, whereas that in the XM201E2 consisted of a "hotter" triple-based M30A1 propellant. The introduction of the hotter triple-based propellant was counterbalanced in the charge by the addition of a TiO_2 /wax wear reducing liner which was expected to maintain equivalent tube wear life.

During the later stages of engineering development of the XM201E2 charge, firing tests indicated unexpectedly high wear of the M185 cannon. It was speculated that the base ignition technique utilized in the XM201E2 charge diminished the performance of TiO_2 /wax liner toward reducing wear, but other causes were also possible. It was felt that immediate diagnostic action was needed to permit timely type classification and attainment of potential savings to be accrued from early productions of the less expensive XM201E2 charges.

Normally the evaluation of the erosion characteristics of particular ammunition charges would require a great number of tests to investigate each charge, and thus would be a prolonged and costly program. Fortunately, however, Calspan through pioneering work for Picatinny in studies of erosion of the eight-inch howitzer (Ref. 1), had developed thermal and erosion/wear sensing techniques which require only a few shots to determine the thermal and erosion/wear characteristics of an individual tube-ammunition combination. Using in-depth thermocouples and analysis, only a single shot is required to generate

data sufficient to determine the heating parameters governing the temperature response of the tube walls during and after firing. Novel erosion sensors exposed to the propellant gases at the bore surface can indicate surface loss as small as one-millionth of an inch. Hence, meaningful erosion measurements may be made in only a few shots. Therefore, in order to further evaluate the XM201E2 charge in comparison with others and to explore possible methods to reduce its erosiveness, a field test program was undertaken using Calspan's thermal and erosion sensing techniques in an instrumented 155mm M185 tube with test firings of selected charges conducted at Picatinny Arsenal.

It was found, as reported in Reference 2, that XM201E2 charges containing a 0.5 oz. black powder spot basepad for faster ignition and additional wear additive were less erosive than the basic XM201E2 charge. Subsequent testing of a modified XM201E2 charge containing a "spot" basepad and a 12 oz. external additive jacket showed much improved wear performance in a successful 3000 round field wear test at Yuma Proving Ground (YPG).

Utilization of the separate external jacket under combat conditions is less desirable than that of an integral charge; therefore, work was undertaken to evaluate the relative wear performance of charges containing different amounts of internal liner with incorporation of the "spot" basepad. The results are given in this report.

Data regarding heating and erosion in the 105mm howitzer firing XM200 and XM622 cartridges are desired for comparison purposes. Taking advantage of the heating/erosion evaluation techniques and scheduled firing test at Picatinny on the 155mm howitzer, Calspan was asked to instrument a 105mm tube (XPL 205) with thermal and erosion sensors and to determine relative performance of the XM622 and XM200 cartridges in exploratory firing tests. Results are given in this technical report.

II. TEST PREPARATIONS

The study employed an experimental-analytical approach in which single-shot test firing data provided a basis for judgment concerning magnitude of erosion/wear conditions in the tube and the efficacy of selected ammunition modifications toward reducing tube wear. The experimental work required the fabrication of suitable thermal/erosion instrumentation.

A. 155MM CANNON

The M185 tube instrumentation is described in detail in Reference 2 and for this reason is not presented in detail here. In brief, heating of the tube was determined through in-depth thermocouples placed at 100 (39.6), 211 (83), and 600 cm (236.5 inches) from the breech face. These were located at nominally 1mm (0.040 inch) of the bore surface. Thermocouple installation at the 1/3 tube and muzzle locations are as presented in Ref. 2. At the origin (100 cm), due to thermocouple burnthrough at this location in the firings of Reference 2, a special removable thermocouple probe was constructed to be compatible with the erosion sensor ports at this location. This thermocouple probe was used to record temperature data at this location in shots where only the steel erosion sensor was installed. This occurred twice for each series tested. Thus, temperature data were taken at this location for only two rounds of each series. Reduction of the recorded temperature data to heat input and peak bore surface temperature was as given in Reference 2.

The erosion sensor installation was invariant from that used in the prior work and reported in Reference 2. Sensors were constructed of Inconel and chrome-moly-vanadium steel. The steel sensors were subjected to five shots, whereas the more erosive Inconel sensors were subjected to three shots each. In these firings, muzzle erosion was not measured, it being inconsequential.

The details of construction and application of the sensors to measurement of tube wear/erosion are given in Ref. 2. Briefly, the surface of each

sensor was made to contain a number of microhardness impressions of different depths as made by changing the load on a microhardness tester and employing a diamond indenter of the "Knoop" type. The indenter produces a sharp impression with a constant ratio of length-to-depth of 30:1 independent of load. The impressions serve as a gauge by which the erosion or wear may be measured after firing. Each sensor surface is characterized prior to and after firing using the Scanning Electron Microscope (SEM). Material loss from firing is indicated by change in impression length or, in the event of very minor erosion, by removal of surface polishing marks which are only a few microinches deep.

B. 105MM HOWITZER

Instrumentation of the 105mm tube (XPL205) consisted of the installation of three ports to be utilized for the placement of erosion sensors and three wells for the placement of thermal sensors (thermocouples). Erosion sensors were placed at 39.7 cm (15.625 in.), 55 cm (21.625 in.) and 70 cm (27.625 in.) from the breech end of the tube and at about the 11 o'clock position. These ports were drilled through to the bore of the tube at the center of a land. It was felt that comparisons of land wear in this howitzer would be the best performance indicator.

The three thermocouple wells were placed along the tube at 39.7 cm (15.625 in.) from the breech face, and at 2.54 cm (1 in.) and 182.8 cm (72 in.) from the muzzle. Each well was flat-bottom drilled to a measured distance of nominally 1 mm (.040 in.) from the bore surface at the center of a groove. Again, Reference 2 presents a detailed description of thermocouple installation and data reduction.

Erosion sensors for use in the 105mm firings were constructed in similar fashion to those used in the 155mm tests, the basic sensor material was, however, Vascomax 300 maraging steel in the solution annealed condition. This material was selected for its known susceptibility to erosion; it being a high (18 percent) nickel alloy. Because erosion in the 105mm howitzer under test was expected to be small in the limited number of rounds available (5 rounds of each type), it was felt necessary to utilize the more sensitive Vascomax

material in order to amplify differences between test charges. It was felt that rotating band forces on the sensor face preclude the use of the very soft Inconel sensor, although these are even more sensitive to erosion than is Vascomax steel. A set of three sensors was also made using chrome-moly-vanadium steel to allow comparison of erosion. All sensors were outfitted with "Knoop" impressions and characterized as to surface condition prior to test using the Scanning Electron Microscope.

III. GENERAL TEST SCOPE AND PROCEDURES

A. TEST SCOPE

Heat transfer and erosion data were obtained in a total of 75 test firings conducted at Picatinny Arsenal with Calspan personnel in attendance. General test procedure was to load and fire test charges at a rate governed by required recording of thermal data and installation of erosion sensors. Typically, ten to fifteen minutes elapsed between test shots. At this firing rate, steady state temperature of the tube was only a few degrees above ambient and was not an influencing factor on erosion or heat input data derived.

In the test firing series, typical measurements included: 1) peak chamber pressure via copper crusher gauges, 2) tube in-wall temperatures, 3) bore erosion via erosion sensors, 4) projectile velocity. In addition, the chamber and bore were visually examined after each shot.

1. 155MM CANNON

Test rounds of a specific type (test group) were fired consecutively. After each test group involving charges containing erosion reducing additives, at least two M4A2 Zone 7 charges were fired as cleaning rounds. Their purpose was to reduce the possible carryover of the effect of the additive to the following test group. Erosion and heating data were routinely gathered for the M4A2 charges as an additional control round. Such cleaning rounds were also fired at the beginning of each day's testing. All charges were preconditioned at 70°F.

A brief description of the test charges evaluated in the firing tests is given in Table I. These charges were assembled at Picatinny Arsenal and were selected to explore the influence on heating and erosion of:

1. Unmodified charges as represented by Groups 2, 4, and 8.
2. Change to faster burning basepad, as represented by Group 3.

TABLE I
155MM TEST ROUNDS

<u>GROUP*</u>	
1/6	XM201E2 Mod (12 oz. External Jacket as Tested in 3000 Rd. Wear Test with Normal 9.5 oz. internal liner).
5	XM201E2 Mod A (100% Additional Internal Additive Liner, 19.0 oz.).
7	XM201E2 Mod B (50% Additional Internal Additive Liner, 14.3 oz.).
3	XM201E2 Mod C (Normal 9.5 Oz. Internal Additive Liner).
4/8	XM201E2 (Normal 9.5 oz. Additive Liner: No Black Powder Spot) (Original High Wear Charge)
2	M119 Charge (Reference Rounds)

*Note: All Mod Designs Contain 0.5 Oz. Black Powder Spot Basepad with 2.0 Oz. CBI Powder

3. Amount and deployment of conventional TiO_2 /wax additive with 0.5 oz. black powder spot basepad as represented by Groups 1, 5, 6, and 7.

Details of each charge are given in Table I.

2. 105MM HOWITZER

Test firings of the 105mm howitzer were conducted in similar fashion to those of the 155mm cannon. Again, test groups were fired consecutively. Rounds of three types were tested.

- 1 - M67 standard charge, Zone 7
- 2 - XM760 cartridge with XM200 propelling charge Zone 8
- 3 - XM622 cartridge loaded at APG, Zone 8

These charges were unmodified and needed no further description.

B. DATA REDUCTION FOR HEAT INPUT

Major data reduction in this investigation involved conversion of in-wall thermocouple outputs to total bore heat input per square foot and assessment of amount of erosion indicated by examination of appropriate erosion sensors.

Conversion of in-wall temperature to heat input was based upon the theory derived in Reference 3 where it is shown that bore heat input per square foot is given by the expression

$$Q = \Delta T(\theta) \sqrt{\pi K c \rho \theta} \quad (1)$$

where Q is the bore heat input

$\Delta T(\theta)$ is the indicated change in in-wall temperature at time, θ

K is the thermal conductivity

$c\rho$ is the heat capacity per unit volume

θ is the time after firing.

Data reduction procedure is to apply Equation 1 at successive time intervals of 0.1, 0.2, 0.3 sec, etc., thus resulting in a plot of Q vs. θ . The curve thus produced is nearly asymptotic to the desired heat input.

As an additional indicator of the relative severity of heating conditions, computed interior ballistics data supplied by Picatinny Arsenal were combined with the recorded heat input data to predict the maximum single-shot bore-surface temperature for each 155mm charge type. The Calspan computer code utilized for this computation is described in detail in Reference 3 and for this reason, warrants no further discussion here.

The amount of erosion experienced by each sensor was determined by comparison of its pretest and post test SEM photographs. This comparison was made after careful ultrasonic cleaning as confirmed by use of the SEM in the x-ray mode, and involved visual study of surface condition and measurement of impression length change. Representative photographs of erosion sensors taken before and after testing are presented in Section IV.

IV. TEST RESULTS

A. 155MM CANNON

Utilizing the above instrumentation and techniques, heating and erosion data were gathered for the 155mm M185 tube. Reduced field test data generated for each charge type (or group number) are summarized in Table II. In this table, both ballistics and heating data are presented. Generally, it is noted that equivalent ballistics performance was obtained for the modified XM201E2 charges with measureable changes in bore heating. For all charges, bore heating is observed to diminish with axial distance toward the muzzle. Muzzle heating appears to be from 1/4 to 1/3 that at the origin for most charges.

Of all groups tested only those utilizing the external jacket showed presence of chamber residue. For these, residue amounts ranged from zero to 3/4 square inches in specific shots.

1. TOTAL HEAT INPUT

The heat input indicated for the origin of rifling for the test groups appears to indicate the M119 charge to exhibit least heating (with the exception of the M4A2 cleaning rounds). A generalization for the origin of rifling heating of the XM201E2 mods indicates heat input to be lowered in some proportion with the increase in amount of internal liner used. Least heating was found for the XM201E2 mod containing 19.0 oz. of internal additive. The XM201E2 mod having the 12 oz. external jacket, although showing improvement over the unmodified XM201E2, showed greater origin heating than the mod having 19 oz. internal liner. Because origin heating and erosion are interrelated, one would expect the erosion to be least for the M119 charge followed closely by the XM201E2 charge containing 19.0 oz. internal liner.

A significant factor in assessing the erosivity of a charge is its effect on the maximum bore temperature produced in the firing of any particular shot. It must be noted that as bore temperatures reach levels in excess of

TABLE II

155MM REDUCED BALLISTIC/HEATING TEST DATA

English Units

Group	Charge	Velocity - f/s		Pressure - psi Ave.	psi Sigma	Heat Input - Btu/Ft ²		Average 236.5 in.	Estimated Peak Temp.-°F
		Ave.	Sigma			39.6 in.	83 in.		
1	XM201E2 Mod.	2230	3.6	32,600	200	114	60	42	2010
2	M119	2200	8.3	28,000	430	96.4	67	45	1670
3	XM201E2 Mod. C	2245	5.4	32,700	300	115.9	67	40	2040
4	XM201E2	2239	2.9	31,900	680	113.5	69	42	1980
5	XM201E2 Mod. A	2241	6.4	32,700	480	102.6	62	38	1790
6	XM201E2 Mod.	2223	5.3	31,500	330	106.5	--	38	1860
7	XM201E2 Mod. B	2242	6.6	32,500	290	111.2	--	35	1950
8	XM201E2	2235	6.1	31,500	540	124	--	37	2200
9	M4A2	1861	5.6	25,700	487	84	44	26	1440

TABLE II (CONTINUED)
155MM REDUCED BALLISTIC/HEATING TEST DATA

Metric Units

Group	Charge	Velocity - m/s		Pressure - n/m ²		Heat Input - Cal/cm ²		Estimated Peak Temp. - °R
		Ave.	Sigma	Ave.	Sigma	100 cm.	211 cm.	600 cm.
1	XM201E2 Mod.	679.7	1.09	225	1.38	30.7	16.2	11.3
2	M119	670.5	2.52	193	2.97	26.0	18.1	12.1
3	XM201E2 Mod. C	684.2	1.64	226	2.07	31.3	18.1	10.8
4	XM201E2	682.4	0.88	220	4.7	30.6	18.6	11.3
5	XM201E2 Mod. A	683.0	1.95	226	3.31	27.7	16.7	10.2
6	XM201E2 Mod.	677.5	1.61	217	2.28	28.7	*	10.2
7	XM201E2 Mod. B	683.3	2.0	224	2.00	30.0	*	9.4
8	XM201E2	681.2	1.85	217	3.73	33.4	*	10.0
9	M4A2	567.2	1.70	177	3.32	22.6	11.8	7.0

*Thermocouple Burnthrough

1500°F small temperature changes can affect erosion greatly due to rapid change in material strength at this temperature level. Peak bore temperatures for the charges tested as computed by Calspan are also given in Table II. The standard XM201E2 is shown to reach a peak bore temperature of about 2100°F. This is in comparison with a computed maximum of about 1670°F for the M119 charge. The XM201E2 mod containing the 19 oz. internal liner with an indicated peak temperature of 1790°F shows the closest approach to that of the standard M119 charge.

2. BORE EROSION

Erosion data generated after examination of the erosion sensors is summarized in Table III. A descriptive account of selected sensor surface condition before and after test is further given by the photographs of Figures 1 through 4. Generally, it was found that the XM201E2 mods showed greater erosion than that of the M119 charge. The unmodified XM201E2 showed greatest surface erosion. Figures 1 and 2 illustrate the erosion differences between the M119 charge and the unmodified XM201E2. In Figure 1, compared to the excellent surface condition on steel for the M119 after firing, the steel sensor used in the XM201E2 firings shows obvious surface loss and cracking. Differences are further amplified by the Inconel sensors of Figure 2. Of course, this result was anticipated from the earlier firings of Reference 2. Fortunately, it was also found in that work that erosion severity of the base ignited XM201E2 charge could be reduced considerably through the use of the 0.5 oz. black powder spot basepad and additional wear additive. Of those XM201E2 mods tested in the current work, it was found that increased internal additive resulted in reduced erosion. Hence, the 19 oz. internal additive design resulted in less erosion than the other internal additive designs of lesser additive weight. Furthermore, the erosion exhibited by the sensors for the 19 oz. internal liner design showed indistinguishable differences from that of the 12 oz. jacket (external) additive design shown effective in the 3000 round fired test at Yuma Proving Ground. Figures 3 and 4 illustrate the surface condition of both the steel and Inconel sensors for each of these two best performing designs.

TABLE III

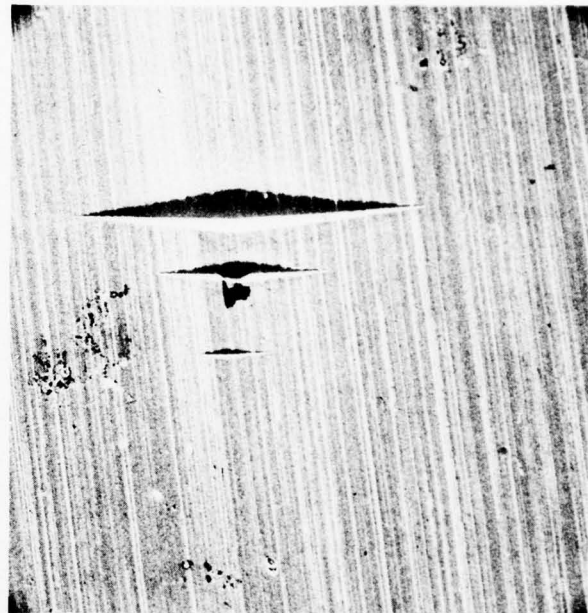
155MM BORE EROSION/CRACKING AT ORIGIN

Group	Charge	Erosion - Steel Microns (Microinches)	Erosion - Inconel Microns (Microinches)	Surface Crack Ranking (1)
1/6	XM201E2 Mod.	.175/.075 (7/3)	.425/.25 (17/10)	2/3
2	M119	.075 (3)	.150 (6)	0
3	XM201E2 Mod. C	.375 (15)	.750+ (30+)	5
4/8	XM201E2	.425/.400 (17/16)	3.00/3.25 (120/130)	9/10
5	XM201E2 Mod. A	.175 (7)	.200 (8)	4
7	XM201E2 Mod. B	.425 (17)	.750 (30)	2

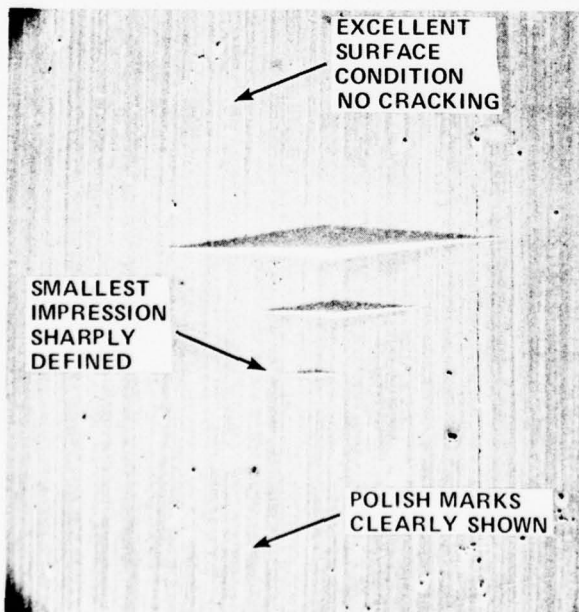
(1) Ranking based upon 0 = no cracks
10 = severe cracks



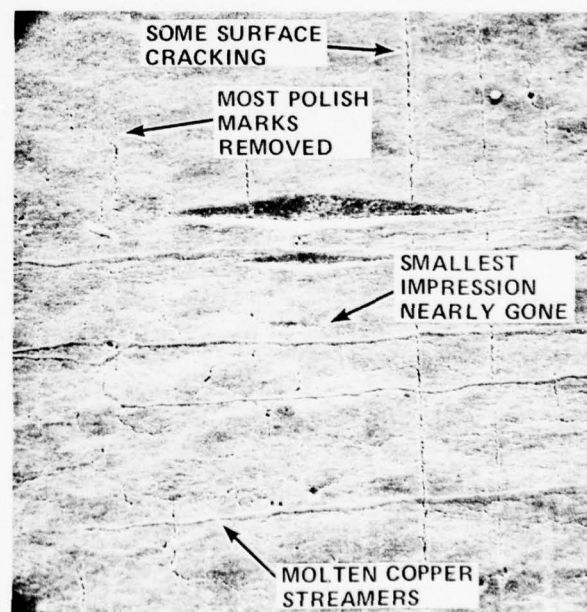
SENSOR FOR GROUP 2 (M119) BEFORE FIRING



SENSOR FOR GROUP 8 (STD. XM 201 E2) BEFORE FIRING

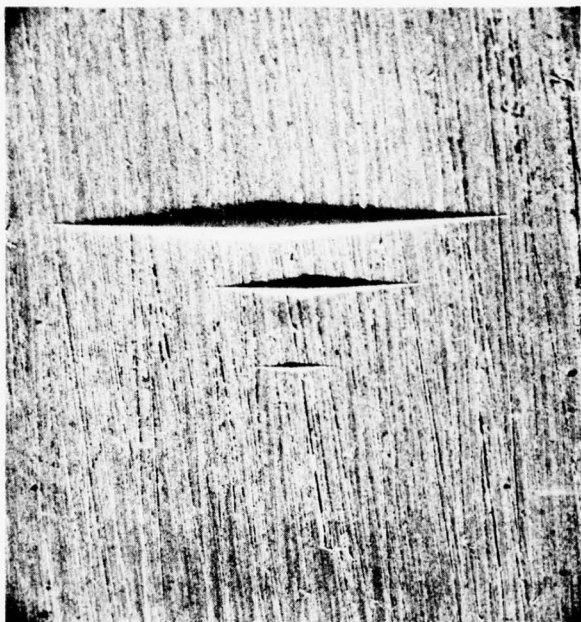


SENSOR AFTER FIVE M119 SHOTS



SENSOR AFTER FIVE (STD. XM 201 E2) SHOTS

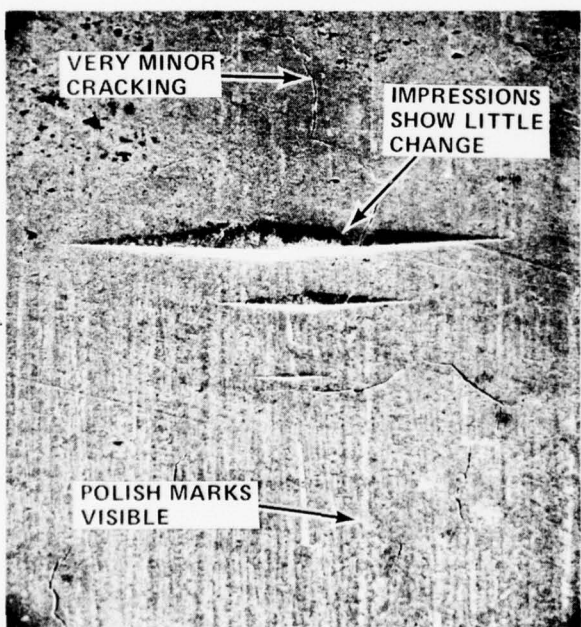
Figure 1 COMPARISON OF STEEL EROSION SENSORS FOR M119 AND UNMODIFIED XM 201 E2 CHARGES (200X)



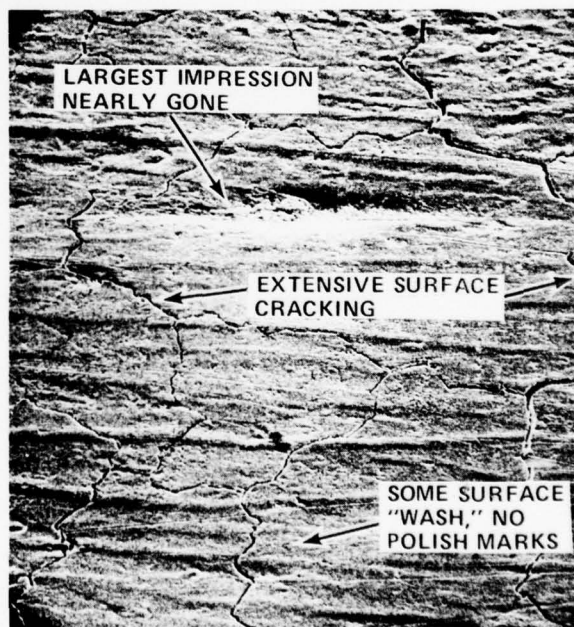
SENSOR FOR GROUP 2 (M119) BEFORE FIRING



SENSOR FOR GROUP 8 (XM 201 E2) BEFORE FIRING



SENSOR FOR GROUP 2 AFTER THREE M119 SHOTS

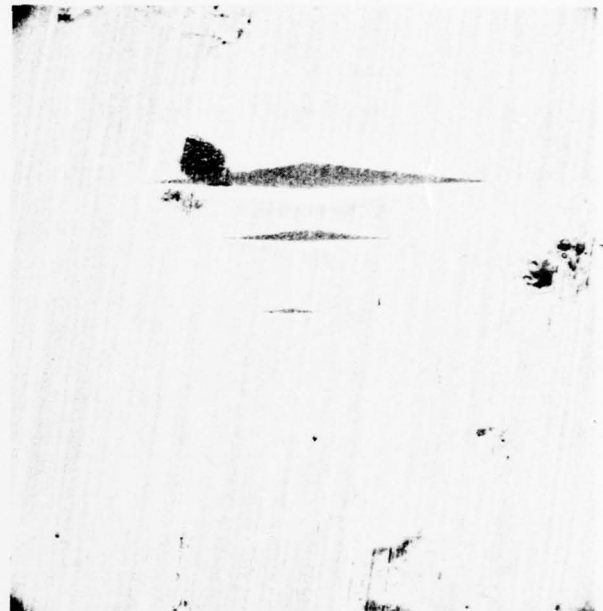


SENSOR FOR GROUP 8 AFTER THREE STD. XM 201 E2 SHOTS

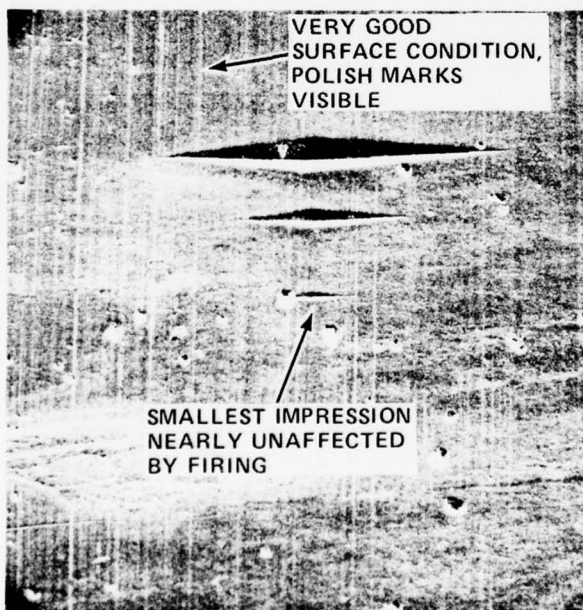
Figure 2 COMPARISON OF EROSION OF INCONEL SENSORS FOR M119 AND UNMODIFIED XM 201 E2 CHARGES (200X)



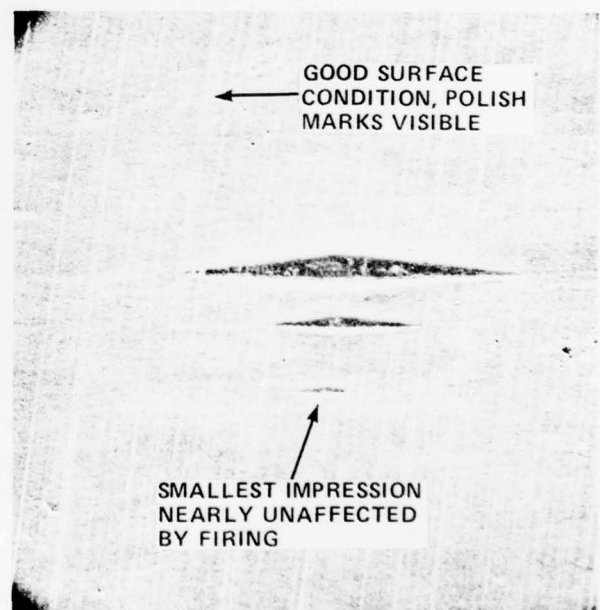
SENSOR FOR GROUP 6 (120Z JACKET) BEFORE FIRING



SENSOR FOR GROUP 5 (190Z LINER) BEFORE FIRING



SENSOR FOR GROUP 6 AFTER FIVE SHOTS

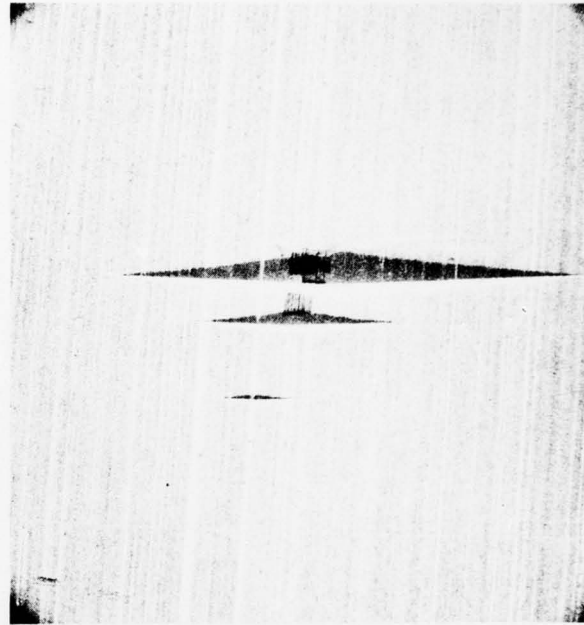


SENSOR FOR GROUP 5 AFTER FIVE SHOTS

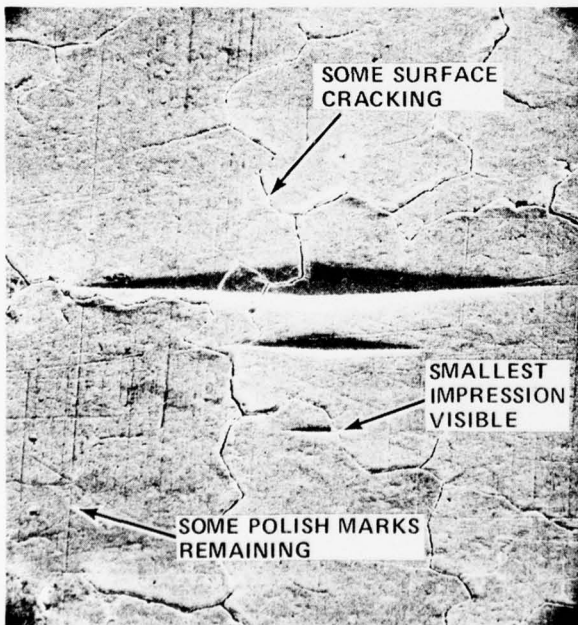
Figure 3 STEEL SENSOR SURFACE CONDITION BEFORE AND AFTER FIRING FOR TWO XM 201 E2 MODS INVOLVING INCREASED WEAR ADDITIVE (200X)



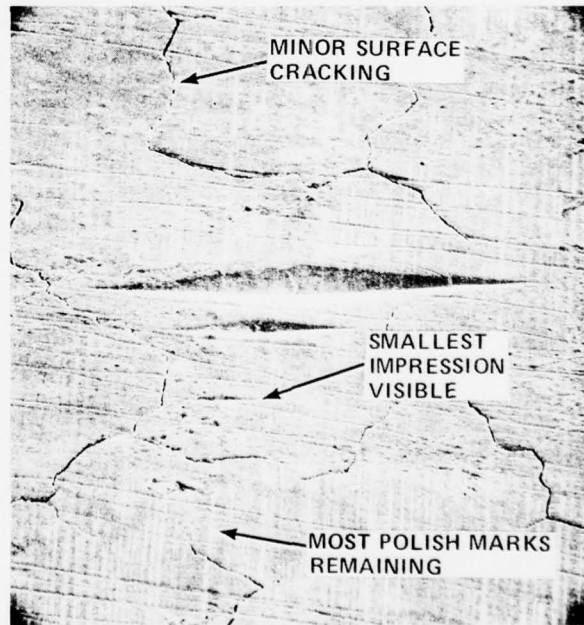
SENSOR FOR GROUP 6 (120Z JACKET) BEFORE FIRING



SENSOR FOR GROUP 5 (190Z LINER) BEFORE FIRING



SENSOR FOR GROUP 6 AFTER THREE SHOTS



SENSOR FOR GROUP 5 AFTER THREE SHOTS

Figure 4 INCONEL SENSOR CONDITION BEFORE AND AFTER FIRING FOR TWO XM 201 E2 MODS INVOLVING INCREASED WEAR ADDITIVE (200X)

The steel sensors for these designs compare favorably with that of the M119 (Figure 1). A comparison of Figures 4 and 2, showing the surface condition of the Inconel sensors, clearly demonstrates the improved performance of these mods over that of the unmodified XM201E2 as well as their degree of approach to erosivity of the M119 charge.

In addition to evaluation of sensor surface loss through impression length change and loss of polishing marks, each was photographed at 2000X magnification and inspected for surface cracking. A qualitative ranking of 0-10 was then established relating to the size and number of cracks. A ranking of 0 indicated no cracking and 10 severe cracking. Each charge group was then ranked with regard to surface cracking with results as given in Table III. Again, the M119 ranked best with the XM201E2 worst. The XM201E2 mods showed intermediate values as indicated.

Reviewing all significant factors of:

1. heating,
2. erosion and cracking of steel,
3. erosion and cracking of Inconel,
4. chamber residue, and
5. practicality of design,

it is recommended that consideration be given to modification of the XM201E2 charge through the addition of a 0.5 oz. black powder spot to the basepad and change to a 19 oz. internal wear liner.

B. 105MM HOWITZER

1. BORE HEAT INPUT

Reduced field test data collected in the 105mm firings are as given in Table IV. Ballistics and heating data as gathered in the tests are shown. Again, as for the 155mm cannon, bore heating is observed to diminish with axial distance along the tube. Actual heating values for all charges tested in the 105mm are considerably below those as recorded in the 155mm tube. In fact, at

TABLE IV

105MM REDUCED BALLISTIC/HEATING TEST DATA

ENGLISH UNITS

Group	Charge	Velocity - f/s Ave.	Pressure - psi Ave.	Sigma	Average Heat Input - Btu/Ft ² Origin	1/2 Tube	Muzzle
1	M67 (Z7)	1699	38,800	8.1	47.5	23	9
2	XM200 (Z8)	2125	43,980	2.1	71.0	44	23
3	XM622 (Z8)	(1)	38,020	(1)	74.5	33.5	21.5
4	XM200 (Z8)	2148	45,320	10.5	71.0	42	23

(1) Not recorded in tests.

TABLE IV (CONTINUED)

105MM REDUCED BALLISTIC/HEATING TEST DATA

METRIC UNITS

Group	Charge	Velocity - m/s Ave. Sigma	Pressure $n/m^2 \times 10^{-6}$ Ave. Sigma	Average Heat Input - cal/cm ² Origin 1/2 Tube Muzzle
1	M67(Z7)	517 2.4	268 2.6	12.8 6.1 2.4
2	XM200(Z8)	647 0.64	303 8.2	19.1 11.8 6.1
3	XM622(Z8)	--- ----	262 7.9	20.0 9.0 5.6
4	XM200(Z8)	654 3.2	313 7.1	19.1 11.3 6.1

the origin of rifling, maximum heating in the 105mm is below even that for the 155mm M4A2 charges. Hence, erosion of the 105mm with the tested charges would naturally be expected to be very minor in the limited complements (5 shots each) used for each group.

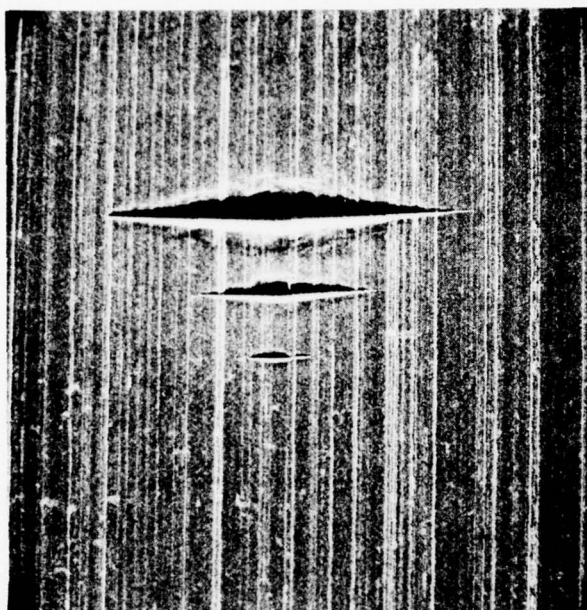
Near the origin of rifling measured bore heat input appears to be lowest for the M67 charges. The XM200 and XM622 charges appear to have nearly the same bore heating with the XM622 showing a few percent greater heating than the XM200. Toward the muzzle, the XM200 charge shows slightly greater heating than the XM622 and 2 to 2.5 times as much heating as the M67 charge. Based on heating alone, one would expect the XM200 and XM622 charges to exhibit about the same erosion and to have greater erosion than the M67 charge.

2. BORE EROSION

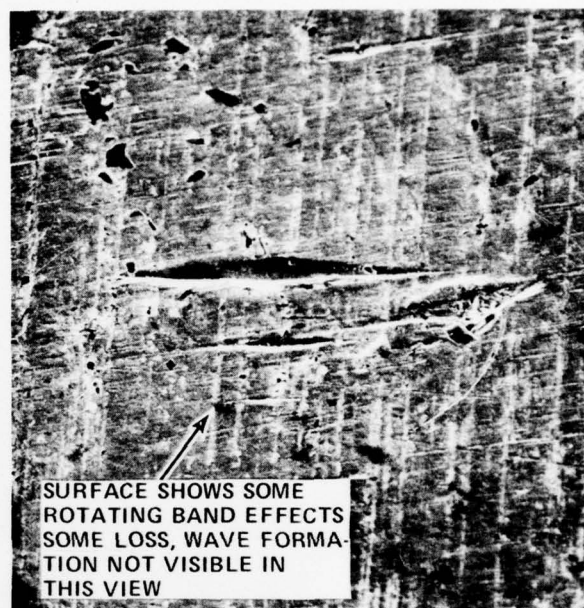
As noted above and anticipated at the outset of the program, conditions within the bore of the 105mm howitzer tested were found to be very mild compared to more energetic cannons such as the eight-inch cannon (ref. 1) or the 155mm cannon. Generally, it was found that erosion of even the sensitive Vascomax sensors placed in the lands was very minimal in 5 shots. Figures 5 through 9 illustrate the sensor surface condition for each type of round tested.

In an attempt to formulate a basis upon which each charge could be ranked with regard to erosivity, erosion sensor condition after test was characterized through analysis of several factors. First, the surface loss was estimated by careful observation of surface quality and impression length change. Resulting estimates are given in Table I. Photographs from which these surface loss estimates were based are shown in Figures 5 through 7.

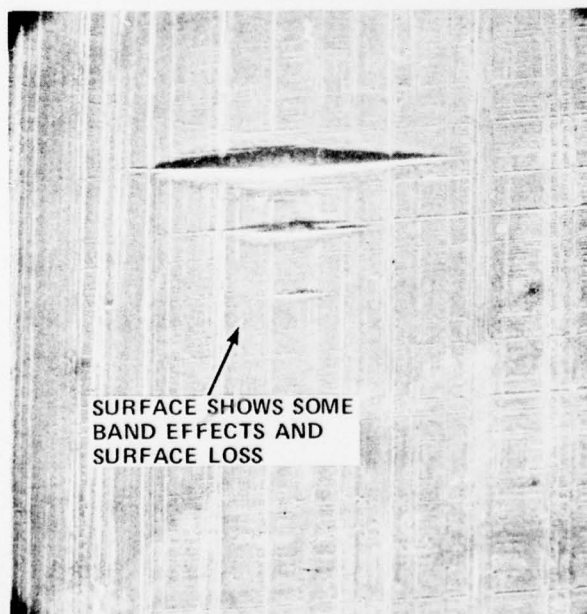
Second, the presence of surface wave formation in varying degrees was observed on each sensor. Inasmuch as this wave pattern, presumably caused by softening of the surface, should be a measure of charge erosivity, each sensor was ranked with respect to the magnitude of wave formation observed. This was accomplished through subjective observation at low magnification as of the type shown in Figure 8. Ranking was based upon 0 indicating no wave formation and



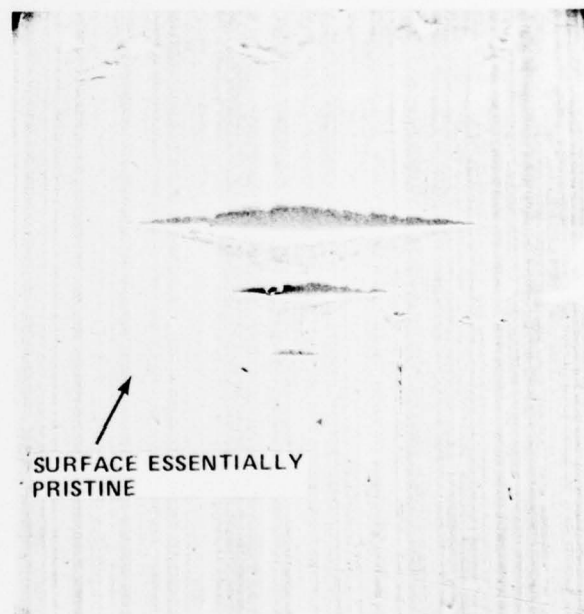
TYPICAL "KNOOP" PATTERN BEFORE FIRING



SENSOR AT 39.6 CM AFTER FIVE SHOTS



SENSOR AT 55 CM AFTER FIVE SHOTS



SENSOR AT 70 CM AFTER FIVE SHOTS

Figure 5 SURFACE CONDITION OF VASCOMAX SENSORS BEFORE AND AFTER FIRING FIVE M67 SHOTS (200X)

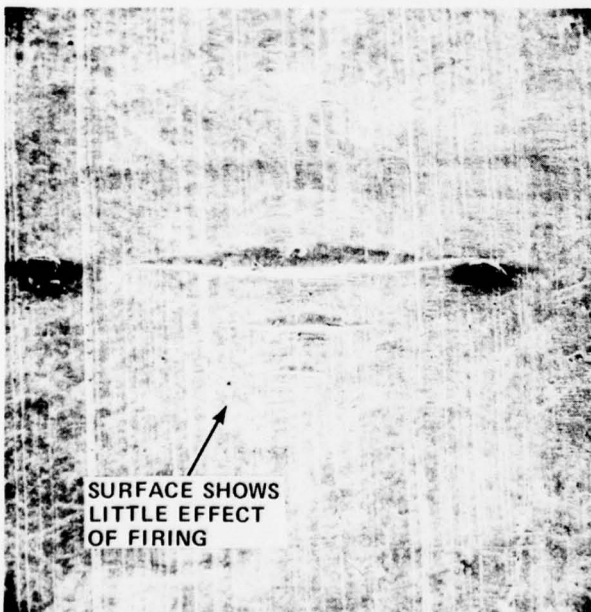


TYPICAL "KNOOP" PATTERN BEFORE FIRING



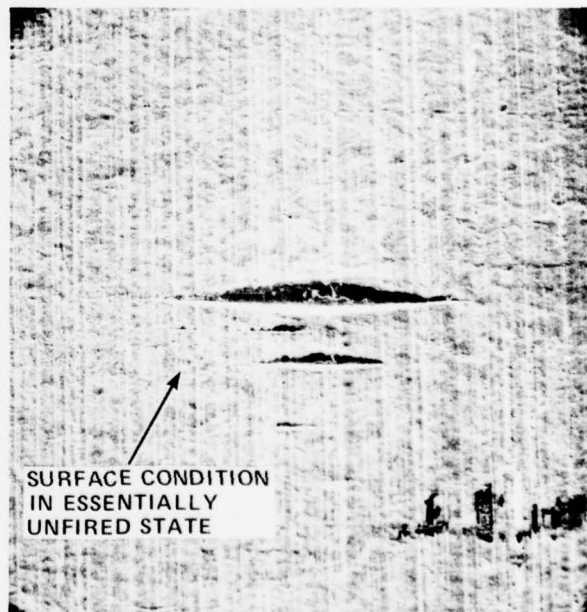
SOME MATERIAL
LOSS, DISTINCT
WAVE FORMATION

SENSOR AT 39.6 CM AFTER FIVE SHOTS



SURFACE SHOWS
LITTLE EFFECT
OF FIRING

SENSOR AT 55 CM AFTER FIVE SHOTS



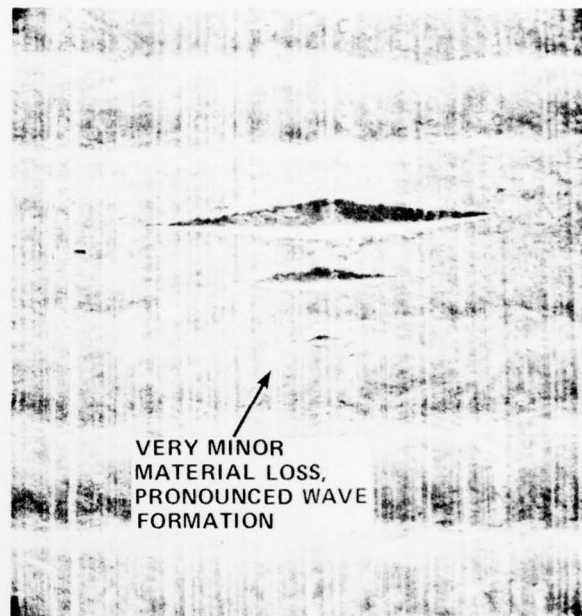
SURFACE CONDITION
IN ESSENTIALLY
UNFIRED STATE

SENSOR AT 70 CM AFTER FIVE SHOTS

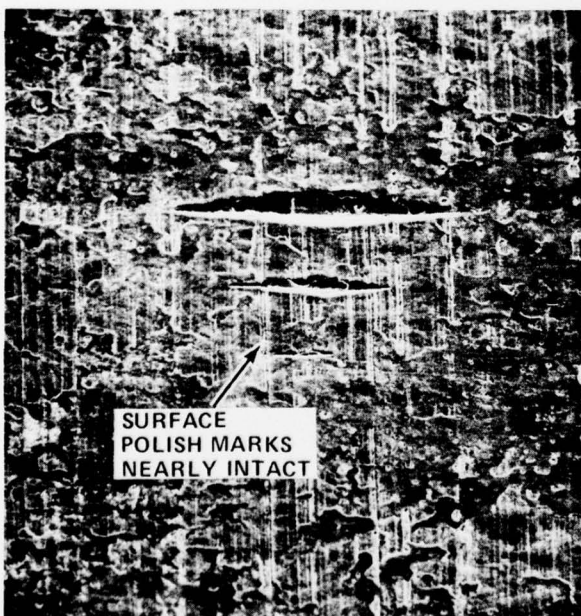
Figure 6 SURFACE CONDITION OF VASCOMAX SENSORS BEFORE AND AFTER FIVE XM 200 SHOTS (200X)



TYPICAL "KNOOP" PATTERN BEFORE FIRING



SENSOR AT 39.6 CM AFTER FIVE SHOTS

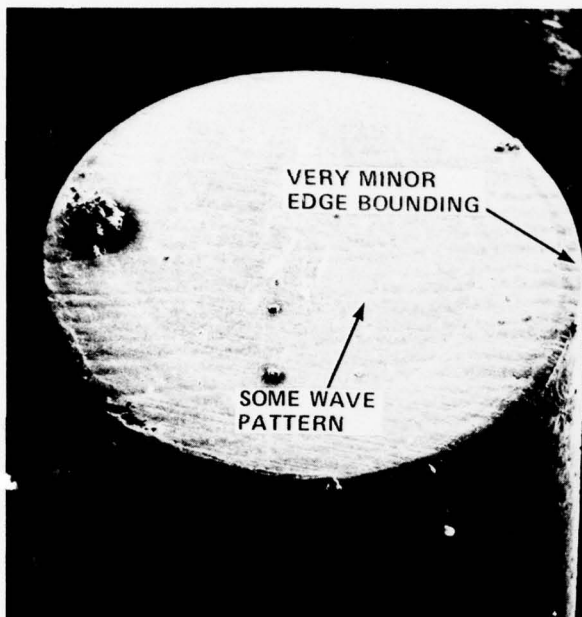


SENSOR AT 55 CM AFTER FIVE SHOTS

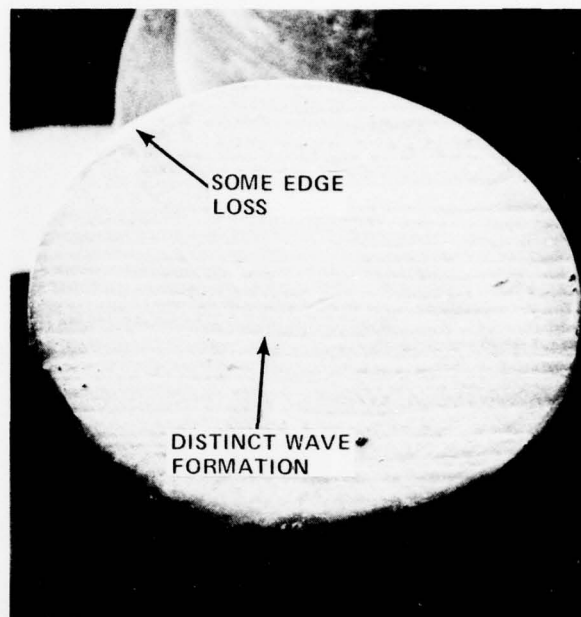


SENSOR AT 70 CM AFTER FIVE SHOTS

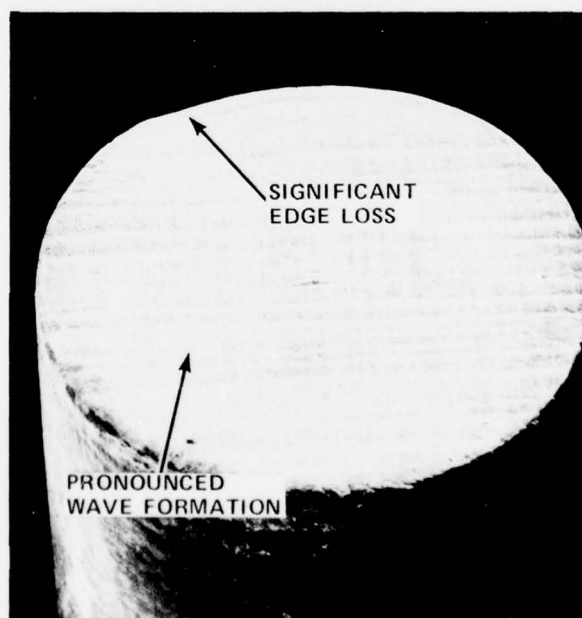
Figure 7 SURFACE CONDITION OF VASCOMAX SENSORS BEFORE AND AFTER FIVE XM 622 SHOTS (200X)



VASCOMAX SENSOR AT 39.6 CM AFTER FIVE M67 SHOTS



VASCOMAX SENSOR AT 39.6 CM AFTER FIVE XM 200 SHOTS



VASCOMAX SENSOR AT 39.6 CM AFTER FIVE XM 622 SHOTS

Figure 8 POST TEST SURFACE WAVE FORMATION ON VASCOMAX EROSION SENSORS LOCATED NEAR THE ORIGIN OF RIFLING (20X)

10 indicating pronounced wave formation. The resulting ranking for each sensor is as given in Table V.

Third, inspection of each sensor under low magnification revealed differences in the amount of edge rounding of the sensor for each charge fired. This is illustrated in Figure 8. Again, as for the wave formation, a similar ranking system was used with regard to the amount of edge rounding on each sensor. These estimates are also given in Table V.

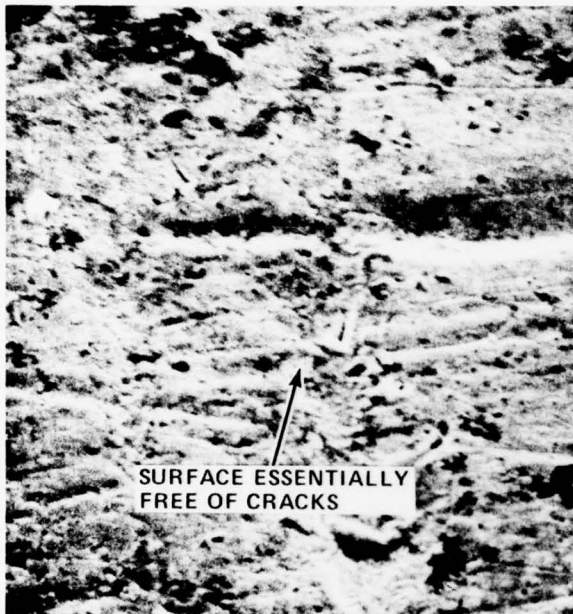
Finally, at very high magnification as is shown in Figure 9, each sensor could be inspected for surface cracking. This was accomplished with similar ranking system to the above. Results are given in Table V.

Relative performance of each charge type was determined by assuming each sensor for a charge type to have equal importance (as if they were at the same location) and weighting each indicator the same so that a direct average could be taken. Table VI gives the average of the indicators as well as the measured average surface loss. As shown, the M67 charge indicates the lowest average (lowest erosivity) in regard to qualitative indicators, surface loss, and heating. The XM200 and XM622 charges are found to have similar values within the accuracy of the ranking estimates and are therefore judged to be of equivalent erosivity.

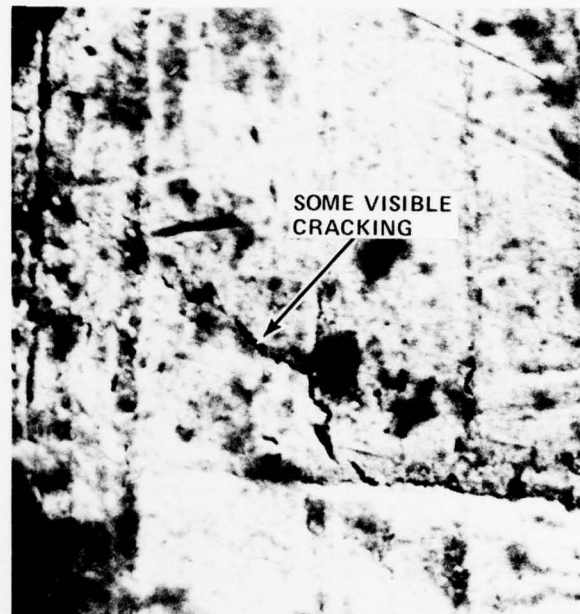
Post test characterization of the chrome-moly-vanadium sensors were used. in the repeat firing of the XM200 charge, as was expected, showed insignificant surface loss or cracking. It would appear that a substantially greater number of shots (say 20-50) are needed if this material type is to provide meaningful discrimination between these mildly erosive 105mm charges.

TABLE V
ESTIMATED EROSION FACTORS

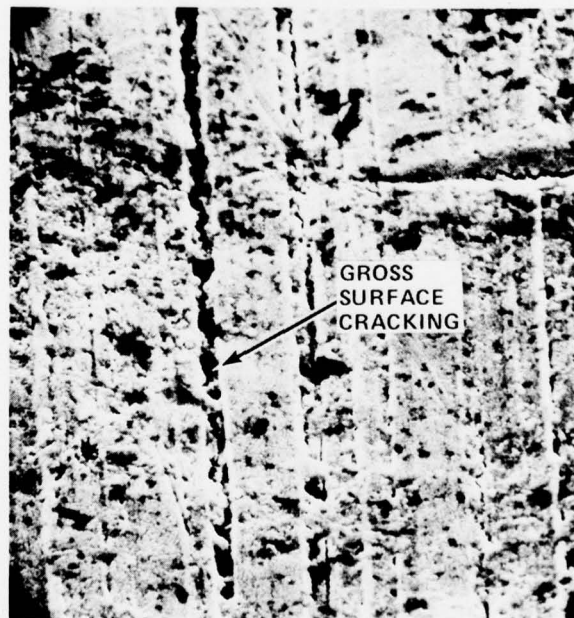
Group	Charge	Position	Relative Ranking			Estimated Loss	
			Wave Formation	Edge Erosion	Surface Cracking	Microns	Microinches
1	M67 (Z7)	Origin	4	4	0	.087	3.5
		6 Inch	0	2	0	.187	7.5
		12 Inch	0	1	0	0	0
2	XM200 (Z8)	Origin	9	9	4	.3	12
		6 Inch	4	4	5	.037	1.5
		12 Inch	3	3	2	.125	5
3	XM622 (Z8)	Origin	10	10	10	.125	5
		6 Inch	4	3	5	0	0
		12 Inch	4	3	2	.9	37



VASCOMAX SENSOR AT 39.6 CM AFTER FIVE M67 SHOTS



VASCOMAX SENSOR AT 39.6 CM AFTER FIVE XM 200 SHOTS



VASCOMAX SENSOR AT 39.6 CM AFTER FIVE XM 622 SHOTS

Figure 9 POST TEST SURFACE CRACK PATTERNS FOR VASCOMAX SENSORS LOCATED NEAR THE ORIGIN OF RIFLING (2000X)

TABLE VI
RELATIVE EROSION PERFORMANCE

Charge	Average Of Indicators*	Origin Heating		Estimated Loss	
		Cal/cm ²	Btu/ft ²	Microns	Microinches
M67	1.2	12.8	47.5	.09	3.6
XM200	4.8	19.1	71	.15	6.1
XM622	5.7	20.0	74.5	.35	14

*Based On 0 = No Effect
10 = Large Effect

V. REFERENCES

1. Vassallo, F.A., "Development of Tube Instrumentation and Shock Tube Gun Techniques for Investigation of Heat Transfer and Erosion in Large Caliber Guns--Eight-Inch Howitzer Studies," Calspan Report No. VL-5337-D-2, December 1976.
2. Vassallo, F.A., "An Evaluation of Heat Transfer and Erosion in the 155mm M185 Cannon," Calspan Technical Report No. VL-5337-D-1, July 1976.
3. Vassallo, F.A., "Mathematical Models and Computer Routines Used in Evaluation of Caseless Ammunition Heat Transfer," Calspan Report No. GM-2948-Z-1, June 1971.